SEARCHES FOR SUPERSYMMETRY WITH THE CMS EXPERIMENT

On behalf of the CMS Collaboration

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OUTLINE

□ Supersymmetry (SUSY) – Symmetry of the Nature?

□ SUSY Production at Colliders

- The Strategy
- The Large Hadron Collider (LHC) Experiment
- The Compact Muon Solenoid (CMS) Detector

□ SUSY Analyses in the CMS Collaboration

- Hadronic SUSY Searches
- Leptonic SUSY Searches

□ Interpretation of the Physics Results

□ Summary

SUPERSYMMETRY

□ Standard Model (SM) describes known particles/forces. Extremely successful at low energy, but several problems:

- Hierarchy problem
- Gauge coupling and non-unification
- Dark matter (DM): preferred explanation WIMP mass $O(100 \text{ GeV}) \rightarrow$ no SM candidate

□ SUSY: popular extension to SM, introduces “super-partners” to each SM particle

- Solves many problems intrinsic to SM
- Lightest SUSY particle (LSP): stable, weakly-interacting particle EWSB scale $\sim 100 \text{ GeV} \rightarrow$ natural DM candidate
- Implies DM may be produced at **LHC**.

SUSY PRODUCTION AT COLLIDERS

- Many SUSY models postulate conserved quantum number:

“R-Parity”

$$R = (-1)^{2S-L+3B}$$

where $\hat{S}$ = spin, L = lepton #, B = baryon #

+1 for SM particles

- 1 for SUSY particles

- ☐ SUSY particles produced in pairs (usually strongly produced squarks/gluinos)
- ☐ LSP is stable
- ☒ Squarks/gluinos decay via cascade, producing jets, (leptons), LSP's spectacular events with several **high p_T jets + (leptons) + E_T^{miss} !**
- ☒ **Strategy: search for excess of events w/ large E_T^{miss} , HT (sum of jet p_T 's)!**

THE LARGE HADRON COLLIDER

- 27km circumference ring on French-Swiss border
- Provides proton-proton collider at 7 TeV center-of-mass-energy
- Data collected by four experiments : **CMS**, **ATLAS**, **LHCb**, **ALICE**

THE CMS EXPERIMENT AND LEPTON-ID

- Most particles are hadrons → electrons/muons very rare
- **Electrons: electromagnetic shower in EM calorimeter → deposit full energy**
- **Muons: minimum ionizing → penetrate deeply into muon system**

SUSY ANALYSES IN THE CMS COLLABORATION

□ In the SUSY processes:

- m_B drives the xsections
- Δm_{bc} drives the hadronic scale
- Δm_{ca} drives the leptonic p_T
- A drives E_{miss}^T

□ The experimental techniques:

- Topology based searches,
not optimized for any particular SUSY model
- E_{miss}^T considered the basis for all the searches
- Try to cover as much phase space as possible
 - Keep the p_T 's as low as possible?

□ Estimate backgrounds from data (data-driven bkg estimate) → minimize reliance on MC

- Especially important for bkg's with detector (mis)reconstruction effects!

SUSY Searches in the CMS Collaboration

Jets + MET	Single lepton + Jets + MET	Opposite-sign di-lepton + jets + MET	Same-sign di-lepton + jets + MET	Multi-lepton	Di-photon + jet + MET	Photon + lepton + MET
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HADRONIC SUSY SEARCHES

Jet+E_{miss}^T analyses:

- **Jets+E_{miss}^T inclusive:** inclusive search – relies on precise determination of all SM backgrounds with robust data-driven techniques
- **Razor:** uses kinematic variables to characterise SUSY pair- production
- **The kinematic variable α_T :** Reduces QCD background substantially
 - ❑ Consider R-Parity conserving SUSY
 - ❑ Strongly interacting *sparticles* dominate
 - ❑ Cascade decay of squarks/ gluinos stable LSP ($\tilde{\chi}_1^0$)
 - ❑ Leads to signature of **E_{miss}^T** and **Jets**

HADRONIC SUSY SEARCHES

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- **Razor:** uses kinematic variables to characterize SUSY pair- production

➤ **The kinematic variable α_T :** Reduces QCD background substantially (2011, 1.1fb⁻¹)

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SUSY-PAS-11-003

SUSY Low Mass (LM) Benchmark Points

m0: unified scalar mass
m1/2: unified gaugino mass
A0: trilinear soft couplings
tan β : $\langle H_u^0 \rangle / \langle H_d^0 \rangle$, sign μ parameter
LM4: 210, 285, 0, 10, + / 1.879pb ($K_{\text{NLO}}=1.35$)
LM6: 85, 400, 0, 10, + / 0.3104pb ($K_{\text{NLO}}=1.3$)

Effective QCD reduction by using kinematic variable:

$$\alpha_T = \sqrt{\frac{p_{T,j_2} / p_{T,j_1}}{2(1 - \cos \Delta \phi)}}$$

QCD : $\cos \Delta \Phi \approx -1$, $\alpha_T \leq 0.5$

Processes with genuine Missing Transverse Energy: $\alpha_T > 0.5$

Jets+ E_{miss}^T analysis with the kinematic variable α_T : Background estimation

SUSY-PAS-11-003

- ✓ The comparisons between data and MC simulation for the H_T variable and the number of reconstructed jets per event, **before the requirement on α_T** .
- ✓ The ratio R_{α_T} exhibits no dependence on H_T if **0.55** is chosen such that the numerator of the ratio in all H_T bins is dominated by $t\bar{t}$, W +jets and $Z \rightarrow \nu\nu$ +jets events

$$R_{\alpha_T} = \frac{\alpha_T > 0.55}{\alpha_T < 0.55}$$

- Electroweak backgrounds: real E_{miss}^T – flat R_{α_T}
- QCD – there is no significant contribution from events from QCD
- Data – ratio consistent with SM background predictions
Use data-driven techniques to estimate W, top, from $W \rightarrow l\nu$, Z background from Gamma +Jets

Jets+ E_{miss}^T analysis with the kinematic variable α_T : Interpretation of Physics Results 2011

SUSY-PAS-11-003

H_T Bin (GeV)	275–325	325–375	375–475	475–575
W + $t\bar{t}$ background	363.7	152.2	88.9	28.8
Z $\rightarrow \nu\bar{\nu}$ background	251.4	103.1	86.4	26.6
QCD background	172.4	55.1	26.9	5.0
Total Background	787.4	310.4	202.1	60.4
Data	782	321	196	62

H_T Bin (GeV)	575–675	675–775	775–875	875– ∞
W + $t\bar{t}$ background	10.6	3.1	0.6	0.6
Z $\rightarrow \nu\bar{\nu}$ background	8.7	4.3	2.5	2.2
QCD background	1.0	0.2	0.1	0.0
Total Background	20.3	7.7	3.2	2.9
Data	21	6	3	1

No evidence, unfortunately, for SUSY in the hadronic channel yet, Up to 1.1 fb^{-1} has been analyzed.

LEPTONIC SUSY SEARCHES

SUSY-PAS-11-010

Jets+Lepton(s) + E_{miss}^T analysis: Same-Sign Di-Lepton Search (2011, $L = 0.98 \text{ fb}^{-1}$)

Same-Sign pairs extremely rare in SM, but appear naturally in many Beyond the Standard Model (BSM) scenarios.

SUSY, Universal Extra Dimensions, SS top pair production, Heavy Majorana neutrinos.

Dominant SM backgrounds:

ttbar with “fake” leptons ($b/c \leftrightarrow e/\mu$)

→ fake ratio / isolation extrapolation

Charge mis-reconstruction

→ use Z's for charge

Rare SM processes: $qq \rightarrow q'q'W^{+/-}W^{+/-}$, ttW

→ estimate from MC

} From Data

Same-Sign Di-Lepton Search: Search Regions

SUSY-PAS-11-010

- ▣ Search for new physics in three complementary samples
 - ▣ **High- p_T leptons:** search for **high lepton p_T**
 - ▣ **Inclusive leptons:** extend search to **low lepton p_T** $\rightarrow$ compensate trigger rate by increasing H_T cut
 - ▣ **Tau – hadrons:** improve sensitivity to 3rd generation
- ▣ Define pre-selection regions in $E_T^{\text{miss}} - H_T$ plane (veto shaded regions)
 - ▣ Validate data-driven background estimates with ~ 10 -100 events
- ▣ Define search regions by adding E_T^{miss}, H_T requirements $\rightarrow$ Data Driven techniques

Same-Sign Di-Lepton Search: Results for 2011

SUSY-PAS-11-010

- Search regions: good agreement between observed yields and predicted background.

Same-Sign Di-Lepton Search: Results for 2011

SUSY-PAS-11-010

CMS preliminary $L_{\text{int}} = 0.98 \text{ fb}^{-1}, \sqrt{s} = 7 \text{ TeV}$

Inclusive & tau-dilepton selections

CMS preliminary $L_{\text{int}} = 0.98 \text{ fb}^{-1}, \sqrt{s} = 7 \text{ TeV}$

High- p_T selections

Predictions for events with one and two fakes, contributions from simulated backgrounds, and those from events with a lepton charge misreconstruction are shown separately.

SS - Di-Lepton Search: Interpretation of Results 2011

SUSY-PAS-11-010

Exclusion region in the CMSSM corresponding to the observed upper limit events

High- p_T selections

Inclusive di-lepton selections

LEPTONIC SUSY SEARCHES

SUSY-PAS-11-011

Jets+Lepton(s) + E_{miss}^T analysis: Opposite-Sign Di-Lepton Search (2011, $L = 0.98 \text{ fb}^{-1}$)

Signature: Opposite-Sign (OS) leptons + ≥ 2 jets + E_{miss}^T

Dominant background: $t\bar{t} \rightarrow \text{di-lepton}$

Perform pre-selection to reject non- $t\bar{t}$ backgrounds

≥ 2 isolated leptons: (e or μ) $p_T > (20, 10) \text{ GeV}$

Reject same-flavor pairs consistent with Z-mass

≥ 2 jets ($p_T > 30 \text{ GeV}$, $|\eta| < 3.0$), $H_T > 100 \text{ GeV}$, $E_{\text{miss}}^T > 50 \text{ GeV}$

Pre-selection region results

Background is $> 90\%$ $t\bar{t}$ (from MC)

Reasonable Data/MC agreement in yields, kinematic distributions

Neutralino decays

$$\chi_2^0 \rightarrow \chi_1^0 \ell^+ \ell^-$$

kinematic edge
(in **SOME** SUSY models)

Opposite-Sign Di-Lepton Search: Results for 2011

SUSY-PAS-11-011

- ☒ Pre-selection region results
- ☒ Background is > 90% $t\bar{t}$ (from MC)
 - ☒ Reasonable **Data/MC** agreement in yields, kinematic distributions

Sample	σ [pb]	total
$t\bar{t} \rightarrow \ell^+ \ell^-$	17	1973.8 ± 19.0
$t\bar{t} \rightarrow \text{fake}$	141	39.0 ± 2.7
$DY \rightarrow \ell^+ \ell^-$	16677	82.8 ± 10.6
$W^+ W^-$	43	17.7 ± 0.9
$W^\pm Z^0$	18	3.8 ± 0.2
$Z^0 Z^0$	5.9	1.2 ± 0.1
single top	102	59.9 ± 1.3
W + jets	96648	20.5 ± 7.1
total SM MC		2198.5 ± 23.1
data		2481
LM1	6.7	167.5 ± 2.6
LM3	5.3	88.6 ± 1.7
LM6	0.5	15.3 ± 0.2

Opposite-Sign Di-Lepton Search: Search Regions

	high E_T^{miss} signal region	high H_T signal region
observed yield	8	4
MC prediction	7.3 ± 2.2	7.1 ± 2.2
ABCD' prediction	4.0 ± 1.0 (stat) ± 0.8 (syst)	4.5 ± 1.6 (stat) ± 0.9 (syst)
$p_T(\ell\ell)$ prediction	14.3 ± 6.3 (stat) ± 5.3 (syst)	10.1 ± 4.2 (stat) ± 3.5 (syst)
N_{bkg}	4.2 ± 1.3	5.1 ± 1.7
non-SM yield UL	10	5.3
LM1	49 ± 11	38 ± 12
LM3	18 ± 5.0	19 ± 6.2
LM6	8.1 ± 1.0	7.4 ± 1.2

$E_T^{\text{miss}} > 275 \text{ GeV}$
 $H_T > 300 \text{ GeV}$

$E_T^{\text{miss}} > 200 \text{ GeV}$
 $H_T > 600 \text{ GeV}$

- ❑ Estimate background in signal regions with two data-driven techniques:
 - ❑ Factorization (ABCD) method using 2 weakly correlated variables: $y = E_T^{\text{miss}}/\sqrt{H_T}$
 - ❑ $p_T(\ell\ell)$: use $p_T(\ell\ell)$ to model $p_T(\nu\nu) \sim E_T^{\text{miss}}$
 - ❑ N_{bkg} : error-weighted average of 2 predictions
- ❑ Observed yields consistent with MC, data-driven background estimates → **no evidence for SUSY**
- ❑ **Extract 95% CL upper limits on non-SUSY yields**

OS - Di-Lepton Search: Interpretation of Results 2011

SUSY-PAS-11-011

Invariant mass spectrum assuming tri-angular shaped signal

Interpretation of the Physics Results for Summer 2011

SUSY-PAS-11-016

Observed exclusion limits from several 2011 CMS SUSY searches plotted in the CMSSM $(m_0, m_{1/2})$ plane

Jets+E $_{\text{miss}}^t \rightarrow \alpha_T$ variable

Jets+E $_{\text{miss}}^t$ + Leptons $\rightarrow$ SS Search

Jets+E $_{\text{miss}}^t$ + Leptons $\rightarrow$ OS Search

Summary

- ❑ $L = 1 \text{ fb}^{-1}$ of data analyzed by the CMS Collaboration
 - ❑ Unfortunately, no evidence of Supersymmetry
 - ❑ Extended previously explored range of model parameters
 - ❑ Results are presented in the CMSSM scenario just for reference with previous limits.
- ❑ Road-map for SUSY discoveries
 - ❑ Many final states, many different analyses, complementarity between analyses, cross-checks
 - ❑ Data-Driven estimation methods and multiple techniques for different analyses and for different backgrounds
 - ❑ Aim is to set up robust analyses for discoveries and define larger limits
- ❑ Prospects for 2011: expected $L = \sim 3 \text{ fb}^{-1}$ data up to end of this year.

BACKUP SLIDES

- ❑ SUSY related fermion and bosons
- ❑ Minimal Field Content:
 - ❑ Chiral superfields, Gauge (vector) superfields, Higgs superfields
- ❑ Gauge interactions as SM plus SUSY “equivalents”
- ❑ Superpotential:

$$W_{\text{MSSM}} = U^c Y_u Q H_2 - D^c Y_d Q H_1 - E^c Y_e L H_1 + \mu H_1 H_2$$

- ❑ The Soft SUSY breaking Lagrangian

$$\begin{aligned} \mathcal{L}_{\text{soft}} = & \frac{1}{2} (M_1 \tilde{B} \tilde{B} + M_2 \tilde{W} \tilde{W} + M_3 \tilde{g} \tilde{g}) + \text{h.c.} \\ & + m_{\tilde{Q}}^2 \tilde{Q}^* \tilde{Q} + m_{\tilde{U}^c}^2 \tilde{U}^{c*} \tilde{U}^c + m_{\tilde{D}^c}^2 \tilde{D}^{c*} \tilde{D}^c + m_{\tilde{L}}^2 \tilde{L}^* \tilde{L} + m_{\tilde{E}^c}^2 \tilde{E}^{c*} \tilde{E}^c + \text{h.c.} \\ & + m_{H_1}^2 H_1^* H_1 + m_{H_2}^2 H_2^* H_2 + \text{h.c.} \\ & + \tilde{U}^c a_u \tilde{Q} H_2 - \tilde{D}^c a_d \tilde{Q} H_1 - \tilde{E}^c a_e \tilde{Q} H_1 + \text{h.c.} \\ & + b H_1 H_2 + \text{h.c.} \end{aligned}$$

Soft SUSY Breaking parameters can be simplified at the GUT scale: [The CMSSM](#)

$$\begin{aligned} M_3 &= M_2 = M_1 = m_{1/2} \\ m_{\tilde{Q}}^2 &= m_{\tilde{U}^c}^2 = m_{\tilde{D}^c}^2 = m_{\tilde{L}}^2 = m_{\tilde{E}^c}^2 = m_0^2 \\ a_u &= A_0 Y_u \quad a_d = A_0 Y_d \quad a_e = A_0 Y_e \\ b &= B_0 \mu \end{aligned}$$

Gravity Mediated SUSY Breaking: Flavour blind interactions communicate SUSY breaking to MSSM e.g. gravity

$$m_0 \quad m_{1/2} \quad A_0 \quad \text{sign}() \quad \tan \beta$$

The kinematic variable α_T

Event Selections:

- ❑ Events with two or more high- p_T jets, reconstructed using the anti- k_T algorithm ($\Delta R=0.5$)
- ❑ Jets are required to have $E_T > 50$ GeV, $|\eta| < 3$
- ❑ The pseudo-rapidity of the jet with the highest E_T (leading jet) is required to be within $|\eta| < 2.5$, and the transverse energy of each of the two leading jets must exceed 100 GeV.
- ❑ Events in which an isolated lepton (electron or muon) with $p_T > 10$ GeV is identified are rejected to suppress events with genuine missing energy from neutrinos.
- ❑ To select a pure multi-jet topology, events are vetoed in which an isolated photon with $p_T > 25$ GeV is found.
- ❑ Events are required to satisfy $H_T > 275$ GeV.

$$\alpha_T = \frac{E_T^{\text{jet}_2}}{M_T} = \frac{E_T^{\text{jet}_2}}{\sqrt{\left(\sum_{i=1}^2 E_T^{\text{jet}_i}\right)^2 - \left(\sum_{i=1}^2 p_x^{\text{jet}_i}\right)^2 - \left(\sum_{i=1}^2 p_y^{\text{jet}_i}\right)^2}}$$

The dependence of R_{α_T} on H_T when varying the effective cross-section of the four major EWK background components individually by $\pm 15\%$.

The kinematic variable α_T : Triggers

- ❑ HLT_HT250/260/270_MHT60/70/80_v*, Fully Hadronic
- ❑ HLT_Mu5/8/15/20_HT200, Cross Object Trigger (A muon and HT in the event)
- ❑ HLT_Photon75_CalIdVL_IsoL, HLT_Photon90_CalIdVL, HLT_Photon90_CalIdVL_IsoL, Photon Trigger

The kinematic variable α_T : Estimation of Background from $t\bar{t}$ and W + Jets Events using a Muon Control Sample

- An estimate of the backgrounds from unidentified leptons and hadronic tau decays originating from high- p_T W bosons is obtained through the use of a muon control sample.
- In this sample, it is explicitly selected W 's decaying to a muon and a neutrino in the phase-space of the signal. This is performed in the same H_T bins as for the hadronic signal selection.
 - One isolated muon with $p_T > 10$ GeV and $|\eta| < 2.5$.
 - $M_T > 30$ GeV, where M_T is the transverse mass of the W candidate.
 - $\Delta R(\text{jet}, \text{muon}) > 0.5$
 - $\cancel{H}_T / H_T > 0.4$
 - No second isolated muon in the event. This reduces $Z \rightarrow \mu\mu$.
- The number of events from W +jet events in the hadronic selection $W^{\text{had/data}}$ can be estimated from data the event yield, W^{μ}_{data} , of these type of events. The value of this ratio is extracted from the MC simulation.

$$W^{\text{had}}_{\text{data}} = W^{\mu}_{\text{data}} \times \frac{W^{\text{had}}_{\text{MC}}}{W^{\mu}_{\text{MC}}}.$$

H_T Bin (GeV)	275–325	325–375	375–475	475–575
MC $W + t\bar{t}$	$463.0 \pm 16.0_{\text{stat}}$	$171.2 \pm 9.5_{\text{stat}}$	$116.3 \pm 8.3_{\text{stat}}$	$43.7 \pm 5.1_{\text{stat}}$
MC $\mu + \text{jets}$	$407.5 \pm 14.5_{\text{stat}}$	$179.1 \pm 9.6_{\text{stat}}$	$131.6 \pm 8.8_{\text{stat}}$	$48.7 \pm 5.5_{\text{stat}}$
MC Ratio	1.14	0.96	0.90	0.90
Data $\mu + \text{jets}$	389	156	113	39
$W + t\bar{t}$ Prediction	$442.0 \pm 22.4_{\text{stat}} \pm 132.6_{\text{syst}}$	$149.1 \pm 11.9_{\text{stat}} \pm 44.7_{\text{syst}}$	$101.9 \pm 9.6_{\text{stat}} \pm 30.6_{\text{syst}}$	$35.2 \pm 5.6_{\text{stat}} \pm 10.6_{\text{syst}}$
H_T Bin (GeV)	575–675	675–775	775–875	875– ∞
MC $W + t\bar{t}$	$17.5 \pm 3.2_{\text{stat}}$	$5.1 \pm 1.8_{\text{stat}}$	$1.1 \pm 0.7_{\text{stat}}$	$1.8 \pm 1.0_{\text{stat}}$
MC $\mu + \text{jets}$	$13.3 \pm 2.9_{\text{stat}}$	$8.0 \pm 2.3_{\text{stat}}$	$3.2 \pm 1.4_{\text{stat}}$	$0.9 \pm 0.7_{\text{stat}}$
MC Ratio	0.90	0.90	0.90	0.90
Data $\mu + \text{jets}$	17	5	0	0
$W + t\bar{t}$ Prediction	$15.3 \pm 3.7_{\text{stat}} \pm 4.6_{\text{syst}}$	$4.5 \pm 2.0_{\text{stat}} \pm 1.4_{\text{syst}}$	$0.0 \pm 1.0_{\text{stat}}$	$0.0 \pm 1.0_{\text{stat}}$

New Physics with Leptons

$$I_{\text{SO}} = \frac{\left[\sum_{\text{Ecal}} E_T + \sum_{\text{HCAL}} E_T + \sum_{\text{Tracker}} p_T \right]_{dR < 0.3}}{p_T}$$

SS – Dilepton Search: Triggers

Leptonic datasets:

- ee channel:
HLT_Ele17_CaloIdL_CaloIsoVL_Ele8_CaloIdL_CaloIsoVL_v* OR
HLT_Ele17_CaloIdT_TrkIdVL_CaloIsoVL_TrkIsoVL_Ele8_CaloIdT_TrkIdVL_CaloIsoVL_TrkIsoVL_v*
OR
HLT_Ele17_CaloIdT_CaloIsoVL_TrkIdVL_TrkIsoVL_Ele8_CaloIdT_CaloIsoVL_TrkIdVL_TrkIsoVL_v*
OR
- $\mu\mu$ channel: HLT_DoubleMu7_v* OR HLT_Mu13_Mu8_v*
- $e\mu$ channel: HLT_Mu17_Ele8_CaloIdL_v* OR HLT_Mu8_Ele17_CaloIdL_v*

Control regions:

- μ : HLT_Mu8_Jet40_v*
- e : HLT_Ele8_CaloIdL_CaloIsoVL_Jet40_v*

SS –Dilepton Search: Fake Ratio Method

$$\begin{aligned}N_l &= N_{pp} + N_{fp} + N_{ff} = N_{t2} + N_{t1} + N_{t0} \\N_{t0} &= (1-p)^2 N_{pp} + (1-p)(1-f)N_{fp} + (1-f)^2 N_{ff} \\N_{t1} &= 2p(1-p)N_{pp} + [f(1-p) + p(1-f)] N_{fp} + 2f(1-f)N_{ff} \\N_{t2} &= p^2 N_{pp} + pfN_{fp} + f^2 N_{ff}\end{aligned}$$

These equations assume that the prompt and the fake ratios for different leptons are independent of each other. The factors p and $(1-p)$ are weighting (or are averaged over) the distribution of prompt leptons and f and $(1-f)$ are weighing (or are averaged over) the distributions of fake leptons.

$$N_{pp} = \frac{1}{(p-f)^2} [(1-f)^2 N_{t2} - f(1-f)N_{t1} + f^2 N_{t0}]$$

$$N_{fp} = \frac{1}{(p-f)^2} [-2fpN_{t0} + [f(1-p) + p(1-f)] N_{t1} - 2(1-p)(1-f)N_{t2}]$$

$$N_{ff} = \frac{1}{(p-f)^2} [p^2 N_{t0} - p(1-p)N_{t1} + (1-p)^2 N_{t2}]$$

OS – Dilepton Search: Triggers

- HLT_DoubleEle8_CaloIdL_TrkIdVL_HT160_v*
- HLT_DoubleEle8_CaloIdL_TrkIdVL_HT150_v*
- HLT_DoubleMu3_HT160_v*
- HLT_DoubleMu3_HT150_v*
- HLT_Mu3_Ele8_CaloIdL_TrkIdVL_HT160_v*
- HLT_Mu3_Ele8_CaloIdL_TrkIdVL_HT150_v*